INVESTIGATION of MINOR ACTINIDE TRANSMUTATION PROBLEM in BENCHMARK EXPERIMENTS at BFS FACILITY with NEPTUNIUM in FUEL COMPOSITION

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INVESTIGATION OF MINOR ACTINIDE TRANSMUTATION IN NEPTUNIUM FUELLED BFS67 ASSEMBLIES

Aim: Reduction of the growing amount of Neptunium produced in reactors,

Possibility of using fast reactors to burn Neptunium

The **BFS67 experimental programme** in the BFS-1 facility at **IPPE**

to confirm the possibility for a fast reactor design to burn Np237

Np237 is homogenised uniformly in the fuel.

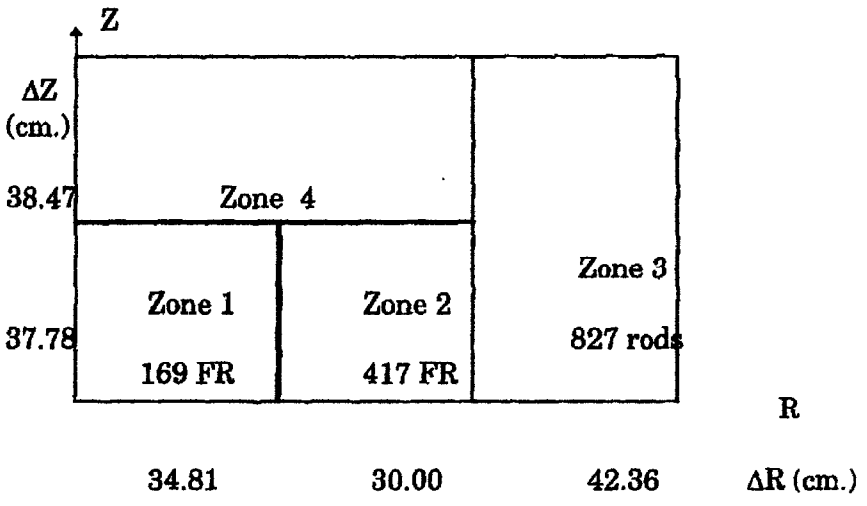
DESCRIPTION OF THE BFS-67 CRITICAL ASSEMBLIES.

The **BFS-67-1** critical assembly is a **reference core**

Zone 1 includes 169 fuel rods with active core cells containing plutonium pellets
(4.4 % of Pu^{240}) with an enrichment of 18.6 %.
Zone 2 (uranium driver zone) includes 417 fuel rods
with active core cells containing uranium pellets with an enrichment of 21.3 %.
Zone 3 is the reflector zone which consists of 827 rods of depleted uranium dioxide

EQUIVALENT PLUTONIUM WORTH

REGION	:pu671		:punp672		:punp673	
ISOTOPE	DENSITY	REACTIVITY WEIGHT	DENSITY	REACTIVITY WEIGHT	DENSITY	REACTIVITY WEIGHT
Np237	5.07E-13	-0.15998	8.47E-04	-0.05742	4.24E-04	-0.09569
U235	2.22E-05	0.70816	1.84E-05	0.65999	2.06E-05	0.68338
U238	5.23E-03	0	4.34E-03	0	4.87E-03	0
Pu239	1.18E-03	1	1.18E-03	1	1.18E-03	1
Pu240	5.72E-05	0.20398	5.71E-05	0.24784	5.70E-05	0.22577
Pu241	3.08E-06	1.34868	3.09E-06	1.26064	3.12E-06	1.30255
Pu242	1.33E-13	0.11812	2.44E-13	0.15729	1.50E-13	0.13835
Am241	1.33E-13	-0.21737	2.44E-13	-0.12256	1.50E-13	-0.16842
Am243	1.33E-13	-0.21689	2.44E-13	-0.12919	1.50E-13	-0.17081
Cm244	1.33E-13	0.28398	2.44E-13	0.34779	1.50E-13	0.31673
Pu238	2.82E-13	0.6282	2.44E-13	0.67335	1.50E-13	0.6516
EQUIVALENT ENRICHMENT	In %	18.67		18.01		17.83
r		0.426		0.488		0.452
K*		1.66162		1.57698		1.59452



R-Z model of BFS-67-1 assembly (1/4 of reactor).

DESCRIPTION OF THE BFS-67 CRITICAL ASSEMBLIES.

- BFS-67-1 reference core

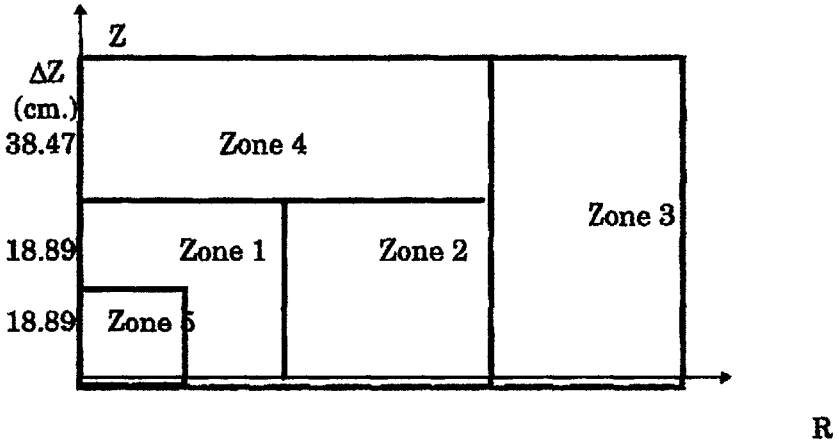
Zone 1 core cells with an enrichment of 18.6 % in Pu (4.4 % of Pu^{240}).
Zone 2 uranium driver zone with an enrichment of 21.3 % in U^{235}.
Zone 3 depleted uranium dioxide

Three other cores have been defined by introducing Np237 in a central core region:

- **BFS67-2** with a central region of 31 drawers
and a **Neptunium enrichment of 13.1%**,

- **BFS67-3** with a central region of the same size but
with a reduced **Neptunium enrichment of 6.5%**,

- **BFS67-3B** with an **enlarged central region** of 61 drawers
and the same **Neptunium enrichment (6.5%)**
as in BFS67-3.



R-Z model of BFS-67-2, 3 and 3B assemblies (1/4 of reactor).

CALCULATIONAL SCHEME

Transposition of experimental results to full power reactors
requires refined calculation analysis,
with particular **attention** being given to the **modelling**
of the **reactor** and **experimental devices**.

JEF2/ECCO/ERANOS calculational scheme includes the required features
- the recent **JEF2** evaluated data file,
- the **ECCO** cell code with a self shielding of cross sections
and a slowing down treatment calculated in 1968 groups
in a **3D representation of the fuel pellets in the assembly tubes** ,
- the S4 P1 transport theory code **BISTRO** for a flux calculation
in a 2D RZ geometrical representation of the cores.

Precise analysis of the experiments performed
using these specific features of the JEF2/ECCO/ERANOS code and data system.

EXPERIMENTAL ANALYSIS (REVISED)

BFS67-1 core with a central enriched plutonium zone surrounded by an uranium driver zone.

Calculated β_{eff} for this core using Tuttle's data is **481 pcm**.

BFS67-2, BFS67-3 and BFS67-3B with Np237 in a central region

JEF2/ECCO/ERANOS results for the critical masses of the four cores

Assembly	**BFS67-1**	**BFS67-2**	**BFS67-3**	**BFS67-3B**
Experiment	1.00038	1.00034	1.00038	1.00048
Calculation	0.99781	0.99711	0.99723	0.99659
Discrepancy (E-C)/C (pcm)	**257**	**323**	**315**	**390**

Excellent agreement , Small trend with the increase in the amount of Np237

Heterogeneity effect included

by a fully 3 dimensional heterogeneous cell description.

CALCULATIONAL SCHEME

JEF2/ECCO/ERANOS calculational scheme includes the recent **JEF2** evaluated data file,

In order to improve the prediction of the calculational scheme
an adjusted data library **ERALIB1 has been created with the help of :**

- **the MASURCA experiments (initial C/E, sensitivities),**
- **the JEF2/ECCO/ERANOS,**
- **the statistical approach.**

Similar analysis of the BFS experiments has been performed
than the one with the JEF2/ECCO/ERANOS code and data system.

EXPERIMENTAL ANALYSIS

BFS67-1 core with a central enriched plutonium zone surrounded by an uranium driver zone.
Calculated β_{eff} for this core using Tuttle's data is **481 pcm**.

BFS67-2, BFS67-3 and BFS67-3B with Np237 in a central region

ERALIB1/ECCO/ERANOS results for the critical masses of the four cores

Assembly	**BFS67-1**	**BFS67-2**	**BFS67-3**	**BFS67-3B**
Experiment	1.00038	1.00034	1.00038	1.00048
Calculation	0.99766	0.99709	0.99714	0.99658
Discrepancy (E-C)/C (pcm)	**273**	**326**	**325**	**391**

Excellent agreement
Heterogeneity effect included
by a fully 3 dimensional heterogeneous cell description.

HETEROGENEOUS EFFECT

BFS67-1 core with a central enriched plutonium zone surrounded by an uranium driver zone.

BFS67-2, BFS67-3 and BFS67-3B with Np237 in a central region

JEF2/ECCO/ERANOS results for the critical masses of the four cores **with either an heterogeneous or an homogeneous description of the cells**

Assembly	**BFS67-1**	**BFS67-2**	**BFS67-3**	**BFS67-3B**
Heterogeneous Calculation	0.99781	0.99711	0.99723	0.99659
Homogeneous Calculation	0.99390	0.99317	0.99330	0.99265
Differences (pcm)	**391**	**394**	**393**	**394**

Significant heterogeneity effect included (around **400 pcm**) by a fully 3 dimensional heterogeneous cell description.

SPECTRAL INDICE MEASUREMENTS

Spectral indices measured in the central region of the three BFS cores
(BFS67-1, BFS67-3B and BFS67-2).

Average fission cross-section ratios measured by three types of ionisation fission chambers:
small-size chambers (SSC),
segment chambers (SC) and
absolute chambers (AC).
For some isotopes the measurements were performed with **solid state detectors (SSD).**

Spectral indice measurements performed **between tubes**
Calculated values taken in the outer regions of the plates of a 3D cell description.

Average capture cross-section ratios (related to the fission of U-235)
measured by means of foils placed in the FR between pellets
and inside a special depleted uranium dioxide pellet (U-238).

Measurements in BFS67-2 carried out also by a French team
using **small fission chambers(SSCFR)**

Different techniques used with different fission chambers give consistent experimental results

CELL Region	pu671 Name		Thickness	Comp.	min	max	U238 Capture	U238 Capture	U235 Fission	Np237 Fission	Np237 Capture	U238 Fission	U238 Capture	U235 Fission	Np237 Fission	Np237 Capture
1	'Na_pure_	in	0.982	1	0	4.077				0.38900	1.36000	0.0000	0.000	0.000	0.218	0.763
2	'UO2_dp_2	in	0.172	2	0	4.077	0.05750	0.23700	1.78000	0.39300	1.35000	0.0323	0.133	0.999	0.221	0.758
3	'UO2_dp_2	in	0.172	2	0	4.077	0.05840	0.23200	1.77000	0.39700	1.34000	0.0328	0.130	0.993	0.223	0.752
4	'UO2_dp_2	in	0.172	2	0	4.077	0.05990	0.23300	1.77000	0.40300	1.33000	0.0336	0.131	0.993	0.226	0.746
5	'SS_ring_	in	0.498	3	0	3.961						0.0000	0.000	0.000	0.000	0.000
6	'Pu_95%__	in	0.322	4	0	3.988						0.0000	0.000	0.000	0.000	0.000
7	'UO2_dp_1	in	0.969	5	0	4.077	0.05900	0.22700	1.77000			0.0331	0.127	0.993	0.000	0.000
8	'Na_pure_	in	0.982	1	0	4.077				0.38900	1.36000	0.0000	0.000	0.000	0.218	0.763
9	'UO2_dp_1	in	0.969	5	0	4.077	0.05700	0.23000	1.78000			0.0320	0.129	0.999	0.000	0.000
10	'Na_pure_	in	0.982	1	0	4.077				0.40500	1.33000	0.0000	0.000	0.000	0.227	0.746
11	'Pu_95%__	in	0.322	4	0	3.988						0.0000	0.000	0.000	0.000	0.000
12	'UO2_dp_2	in	0.172	2	0	4.077	0.06290	0.23500	1.76000	0.41400	1.32000	0.0353	0.132	0.988	0.232	0.741
13	'UO2_dp_2	in	0.172	2	0	4.077	0.06030	0.24000	1.77000	0.40400	1.33000	0.0338	0.135	0.993	0.227	0.746
14	'Al__1.14	in	0.113	6	0	4.148						0.0000	0.000	0.000	0.000	0.000
15	'SS_ring_	in	0.498	3	0	3.961						0.0000	0.000	0.000	0.000	0.000
16	'Na_pure_	in	0.982	1	0	4.077				0.39000	1.36000	0.0000	0.000	0.000	0.219	0.763
17	'UO2_dp_1	in	0.969	5	0	4.077	0.05580	0.23200	1.79000			0.0313	0.130	1.004	0.000	0.000
18	'Na_pure_	out	0.982	7	4.077	4.746	0.05570	0.25900	1.79000	0.38800	1.36000	0.0313	0.145	1.004	0.218	0.763
19	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05630	0.25800	1.78000	0.39000	1.36000	0.0316	0.145	0.999	0.219	0.763
20	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05690	0.25500	1.78000	0.39300	1.35000	0.0319	0.143	0.999	0.221	0.758
21	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05800	0.25500	1.78000	0.39700	1.34000	0.0325	0.143	0.999	0.223	0.752
22	'SS_ring_	out	0.498	9	3.961	4.746						0.0000	0.000	0.000	0.000	0.000
23	'Pu_95%__	out	0.322	10	3.988	4.746						0.0000	0.000	0.000	0.000	0.000
24	'UO2_dp_1	out	0.969	11	4.077	4.746						0.0000	0.000	0.000	0.000	0.000
25	'Na_pure_	out	0.982	7	4.077	4.746	0.05560	0.25700	1.79000	0.38700	1.36000	0.0312	0.144	1.004	0.217	0.763
26	'UO2_dp_1	out	0.969	11	4.077	4.746						0.0000	0.000	0.000	0.000	0.000
27	'Na_pure_	out	0.982	7	4.077	4.746	0.05890	0.25900	1.78000	0.40000	1.34000	0.0331	0.145	0.999	0.224	0.752
28	'Pu_95%__	out	0.322	10	3.988	4.746						0.0000	0.000	0.000	0.000	0.000
29	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05900	0.25900	1.77000	0.40100	1.34000	0.0331	0.145	0.993	0.225	0.752
30	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05730	0.26200	1.78000	0.39400	1.35000	0.0322	0.147	0.999	0.221	0.758
31	'Al__1.14	out	0.113	12	4.148	4.746						0.0000	0.000	0.000	0.000	0.000
32	'SS_ring_	out	0.498	9	3.961	4.746						0.0000	0.000	0.000	0.000	0.000
33	'Na_pure_	out	0.982	7	4.077	4.746	0.05590	0.26500	1.79000	0.38900	1.36000	0.0314	0.149	1.004	0.218	0.763
34	'UO2_dp_1	out	0.969	11	4.077	4.746						0.0000	0.000	0.000	0.000	0.000
	Mean Value	out					0.05707	0.25878	1.78222	0.39322	1.35111	0.0320	0.145	1.000	0.221	0.758

ERALIB1

CELL Region	pu671 Name		Thickness	Comp.	min	max	U238 Fission	U238 Capture	U235 Fission	Np237 Fission	Np237 Capture	U238 Fission	U238 Capture	U235 Fission	Np237 Fission	Np237 Capture
1	'Na_pure_	in	0.982	1	0	4.077	0.00000	0.00000	0.00000	0.39228	1.33759	0.0000	0.0000	0.0000	0.2234	0.7618
2	'UO2_dp_2	in	0.172	2	0	4.077	0.05678	0.23409	1.75437	0.39636	1.32652	0.0323	0.1333	0.9992	0.2257	0.7555
3	'UO2_dp_2	in	0.172	2	0	4.077	0.05771	0.22952	1.74968	0.40013	1.31847	0.0329	0.1307	0.9965	0.2279	0.7509
4	'UO2_dp_2	in	0.172	2	0	4.077	0.05919	0.23048	1.74385	0.40605	1.30789	0.0337	0.1313	0.9932	0.2313	0.7449
5	'SS_ring_	in	0.498	3	0	3.961	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
6	'Pu_95%__	in	0.322	4	0	3.988	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
7	'UO2_dp_1	in	0.969	5	0	4.077	0.05825	0.22467	1.74645	0.00000	0.00000	0.0332	0.1280	0.9947	0.0000	0.0000
8	'Na_pure_	in	0.982	1	0	4.077	0.00000	0.00000	0.00000	0.39164	1.33553	0.0000	0.0000	0.0000	0.2231	0.7606
9	'UO2_dp_1	in	0.969	5	0	4.077	0.05633	0.22770	1.75618	0.00000	0.00000	0.0321	0.1297	1.0002	0.0000	0.0000
10	'Na_pure_	in	0.982	1	0	4.077	0.00000	0.00000	0.00000	0.40844	1.30948	0.0000	0.0000	0.0000	0.2326	0.7458
11	'Pu_95%__	in	0.322	4	0	3.988	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
12	'UO2_dp_2	in	0.172	2	0	4.077	0.06216	0.23196	1.73548	0.41689	1.29178	0.0354	0.1321	0.9884	0.2374	0.7357
13	'UO2_dp_2	in	0.172	2	0	4.077	0.05953	0.23691	1.74519	0.40674	1.30941	0.0339	0.1349	0.9940	0.2317	0.7458
14	'Al__1.14	in	0.113	6	0	4.148	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
15	'SS_ring_	in	0.498	3	0	3.961	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
16	'Na_pure_	in	0.982	1	0	4.077	0.00000	0.00000	0.00000	0.39330	1.33714	0.0000	0.0000	0.0000	0.2240	0.7616
17	'UO2_dp_1	in	0.969	5	0	4.077	0.05515	0.22962	1.76233	0.00000	0.00000	0.0314	0.1308	1.0037	0.0000	0.0000
18	'Na_pure_	out	0.982	7	4.077	4.746	0.05500	0.25528	1.76184	0.39055	1.33903	0.0313	0.1454	1.0034	0.2224	0.7626
19	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05559	0.25400	1.75792	0.39330	1.33243	0.0317	0.1447	1.0012	0.2240	0.7589
20	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05624	0.25121	1.75479	0.39591	1.32701	0.0320	0.1431	0.9994	0.2255	0.7558
21	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05727	0.25100	1.75100	0.40000	1.32003	0.0326	0.1430	0.9973	0.2278	0.7518
22	'SS_ring_	out	0.498	9	3.961	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
23	'Pu_95%__	out	0.322	10	3.988	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
24	'UO2_dp_1	out	0.969	11	4.077	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
25	'Na_pure_	out	0.982	7	4.077	4.746	0.05490	0.25281	1.76062	0.38943	1.33801	0.0313	0.1440	1.0028	0.2218	0.7621
26	'UO2_dp_1	out	0.969	11	4.077	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
27	'Na_pure_	out	0.982	7	4.077	4.746	0.05827	0.25468	1.75026	0.40281	1.31792	0.0332	0.1450	0.9969	0.2294	0.7506
28	'Pu_95%__	out	0.322	10	3.988	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
29	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05833	0.25480	1.74915	0.40354	1.31600	0.0332	0.1451	0.9962	0.2298	0.7495
30	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05665	0.25780	1.75485	0.39713	1.32656	0.0323	0.1468	0.9995	0.2262	0.7555
31	'Al__1.14	out	0.113	12	4.148	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
32	'SS_ring_	out	0.498	9	3.961	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
33	'Na_pure_	out	0.982	7	4.077	4.746	0.05522	0.26035	1.76172	0.39154	1.33841	0.0315	0.1483	1.0034	0.2230	0.7623
34	'UO2_dp_1	out	0.969	11	4.077	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	0.0000	0.0000	0.0000
	Mean Value	out					0.05639	0.25466	1.75579	0.39602	1.32838	0.0321	0.1450	1.0000	0.2256	0.7566

PUNP672.XLS

CELL Region	punp672 Name		Thickness	Comp.	min	max	U238 Fission	U238 Capture	U235 Fission	Np237 Fission	Np237 Capture	U238 Fission	U238 Capture	U235 Fission	Np237 Fission	Np237 Capture
1	'Na_pure_	in	0.986	1	0	4.077	0.00000	0.00000	0.00000	0.43704	1.10935	0.00000	0.00000	0.00000	0.27055	0.68675
2	'NpO2____	in	0.975	2	0	4.077	0.00000	0.00000	0.00000	0.45134	1.08469	0.00000	0.00000	0.00000	0.27940	0.67148
3	'Pu_95%__	in	0.323	3	0	3.988	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	'UO2_dp_1	in	0.972	4	0	4.077	0.06658	0.20255	1.61235	0.43871	1.10582	0.04121	0.12539	0.99813	0.27158	0.68456
5	'Na_pure_	in	0.986	1	0	4.077	0.00000	0.00000	0.00000	0.42924	1.12282	0.00000	0.00000	0.00000	0.26572	0.69509
6	'UO2_dp_1	in	0.972	4	0	4.077	0.06450	0.20479	1.61971	0.43087	1.11934	0.03993	0.12677	1.00269	0.26673	0.69293
7	'Na_pure_	in	0.986	1	0	4.077	0.00000	0.00000	0.00000	0.44606	1.10071	0.00000	0.00000	0.00000	0.27614	0.68140
8	'Pu_95%__	in	0.323	3	0	3.988	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9	'NpO2____	in	0.975	2	0	4.077	0.00000	0.00000	0.00000	0.45161	1.08559	0.00000	0.00000	0.00000	0.27957	0.67204
10	'Na_pure_	in	0.986	1	0	4.077	0.00000	0.00000	0.00000	0.43718	1.10981	0.00000	0.00000	0.00000	0.27064	0.68703
11	'UO2_dp_1	in	0.972	4	0	4.077	0.06461	0.20530	1.61753	0.43175	1.11591	0.04000	0.12709	1.00134	0.26727	0.69081
12	'Na_pure_	out	0.986	5	4.077	4.746	0.06467	0.21888	1.61578	0.43409	1.11227	0.04003	0.13550	1.00025	0.26872	0.68855
13	'NpO2____	out	0.975	6	4.077	4.746	0.06722	0.21693	1.60788	0.44369	1.09723	0.04161	0.13429	0.99536	0.27467	0.67924
14	'Pu_95%__	out	0.323	7	3.988	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15	'UO2_dp_1	out	0.972	8	4.077	4.746	0.06504	0.21584	1.61523	0.43494	1.11122	0.04026	0.13362	0.99991	0.26925	0.68790
16	'Na_pure_	out	0.986	5	4.077	4.746	0.06302	0.21708	1.62216	0.42713	1.12413	0.03901	0.13438	1.00420	0.26442	0.69590
17	'UO2_dp_1	out	0.972	8	4.077	4.746	0.06363	0.21775	1.62062	0.42965	1.12092	0.03939	0.13480	1.00325	0.26598	0.69391
18	'Na_pure_	out	0.986	5	4.077	4.746	0.06648	0.21860	1.61362	0.44058	1.10655	0.04115	0.13533	0.99892	0.27274	0.68501
19	'Pu_95%__	out	0.323	7	3.988	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
20	'NpO2____	out	0.975	6	4.077	4.746	0.06720	0.21939	1.60858	0.44377	1.09817	0.04160	0.13581	0.99580	0.27472	0.67983
21	'Na_pure_	out	0.986	5	4.077	4.746	0.06467	0.22021	1.61613	0.43415	1.11273	0.04003	0.13632	1.00047	0.26876	0.68884
22	'UO2_dp_1	out	0.972	8	4.077	4.746	0.06387	0.21790	1.61837	0.43097	1.11722	0.03954	0.13489	1.00186	0.26679	0.69162
	Mean Value	out					0.06509	0.21806	1.61537	0.43544	1.11116	0.04029	0.13499	1.00000	0.26956	0.68787

CELL	punp673						U238	U238	U235	Np237	Np237	U238	U238	U235	Np237	Np237
Region	Name		Thickness	Comp.	min	max	Fission	Capture	Fission	Fission	Capture	Fission	Capture	Fission	Fission	Capture
1	'Na_pure_	in	0.981	1	0	4.077	0.00000	0.00000	0.00000	0.40740	1.23119	0.00000	0.00000	0.00000	0.24118	0.72886
2	'UO2_dp_2	in	0.172	2	0	4.077	0.06070	0.22191	1.69010	0.41100	1.22318	0.03594	0.13137	1.00053	0.24331	0.72412
3	'UO2_dp_2	in	0.172	2	0	4.077	0.06156	0.21847	1.68671	0.41441	1.21706	0.03644	0.12934	0.99853	0.24533	0.72049
4	'UO2_dp_2	in	0.172	2	0	4.077	0.06295	0.21902	1.68231	0.41990	1.20865	0.03727	0.12966	0.99592	0.24858	0.71552
5	'SS_ring_	in	0.497	3	0	3.961	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6	'Pu_95%__	in	0.321	4	0	3.988	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7	'UO2_dp_1	in	0.967	5	0	4.077	0.06195	0.21465	1.68543	0.00000	0.00000	0.03667	0.12707	0.99777	0.00000	0.00000
8	'Na_pure_	in	0.981	1	0	4.077	0.00000	0.00000	0.00000	0.40585	1.23260	0.00000	0.00000	0.00000	0.24026	0.72969
9	'UO2_dp_1	in	0.967	5	0	4.077	0.06024	0.21752	1.69137	0.00000	0.00000	0.03566	0.12877	1.00128	0.00000	0.00000
10	'Na_pure_	in	0.981	1	0	4.077	0.00000	0.00000	0.00000	0.42370	1.20449	0.00000	0.00000	0.00000	0.25083	0.71305
11	'Pu_95%__	in	0.321	4	0	3.988	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12	'NpO2____	in	0.97	6	0	4.077	0.00000	0.00000	0.00000	0.42868	1.18688	0.00000	0.00000	0.00000	0.25377	0.70263
13	'Na_pure_	in	0.981	1	0	4.077	0.00000	0.00000	0.00000	0.41310	1.21846	0.00000	0.00000	0.00000	0.24455	0.72132
14	'UO2_dp_1	in	0.967	5	0	4.077	0.05957	0.21847	1.69327	0.00000	0.00000	0.03526	0.12933	1.00241	0.00000	0.00000
15	'Na_pure_	out	0.981	7	4.077	4.746	0.05892	0.23682	1.69531	0.40547	1.23252	0.03488	0.14019	1.00362	0.24003	0.72965
16	'UO2_dp_2	out	0.172	8	4.077	4.746	0.05943	0.23584	1.69280	0.40787	1.22801	0.03518	0.13962	1.00213	0.24146	0.72698
17	'UO2_dp_2	out	0.172	8	4.077	4.746	0.06004	0.23379	1.69051	0.41026	1.22384	0.03554	0.13840	1.00078	0.24287	0.72451
18	'UO2_dp_2	out	0.172	8	4.077	4.746	0.06102	0.23353	1.68765	0.41404	1.21828	0.03612	0.13825	0.99908	0.24511	0.72122
19	'SS_ring_	out	0.497	9	3.961	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
20	'Pu_95%__	out	0.321	10	3.988	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
21	'UO2_dp_1	out	0.967	11	4.077	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
22	'Na_pure_	out	0.981	7	4.077	4.746	0.05865	0.23535	1.69596	0.40370	1.23427	0.03472	0.13933	1.00400	0.23899	0.73068
23	'UO2_dp_1	out	0.967	11	4.077	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24	'Na_pure_	out	0.981	7	4.077	4.746	0.06229	0.23806	1.68402	0.41795	1.21175	0.03687	0.14093	0.99693	0.24743	0.71735
25	'Pu_95%__	out	0.321	10	3.988	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
26	'NpO2____	out	0.97	12	4.077	4.746	0.06288	0.23960	1.67830	0.42065	1.20261	0.03722	0.14184	0.99355	0.24902	0.71194
27	'Na_pure_	out	0.981	7	4.077	4.746	0.06013	0.24056	1.68901	0.41012	1.22188	0.03560	0.14241	0.99989	0.24279	0.72335
28	'UO2_dp_1	out	0.967	11	4.077	4.746	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
							0.06042	0.23669	1.68920	0.41126	1.22165	0.03577	0.14012	1.00000	0.24346	0.72321

SPECTRAL INDICE MEASUREMENTS (REVISED)

Spectral indice measurements performed **between tubes**
Calculated values taken in the outer regions of the plates of a 3D cell description.

C/E for Spectral Indices with JEF2/ECCO/ERANOS

Assemblies	BFS-67-1	BFS-67-3B	BFS-67-2
σ_fU238/σ_fU235	0.985±0.025	0.996±0.025	1.035±0.025
σ_fPu239/σ_fU235	0.986±0.015	0.995±0.015	1.003±0.015
σ_fNp237/σ_fPu239	0.936±0.030	0.980±0.030	0.979±0.030
σ_fPu238/σ_fPu239	1.032±0.035	1.042±0.035	1.046±0.035
σ_fPu240/σ_fPu239	1.032±0.030	1.061±0.030	1.067±0.030
σ_fPu241/σ_fPu239	1.022±0.015	1.017±0.015	1.008±0.015
σ_fPu242/σ_fPu239	1.011±0.020	1.046±0.020	1.053±0.020
σ_fAm241/σ_fPu239	0.926±0.030	0.962±0.030	0.964±0.030
σ_fAm243/σ_fPu239	0.955±0.040	1.026±0.040	1.007±0.040
σ_fCm244/σ_fPu239	1.127±0.030	1.115±0.030	1.110±0.030
σ_cU238/σ_fU235	0.987±0.025	0.930±0.025	0.937±0.025
σ_cAu197/σ_fU235	0.968±0.045	-	0.890±0.045
σ_cNp237/σ_cU238	0.960±0.050	0.938±0.035	0.960±0.050
σ_cNp237/σ_fU235	1.012±0.035	-	0.969±0.035

SPECTRAL INDICE MEASUREMENTS

Spectral indice measurements performed **between tubes**
Calculated values taken in the outer regions of the plates of a 3D cell description.

C/E for Spectral Indices with ERALIB1/ECCO/ERANOS

Assemblies	BFS-67-1	BFS-67-3B	BFS-67-2
σ_fU238/σ_fU235	0.988±0.025	0.995±0.025	1.026±0.025
σ_fPu239/σ_fU235	1.003±0.015	1.012±0.015	1.018±0.015
σ_fNp237/σ_fPu239	0.944±0.030	0.993±0.030	0.998±0.030
σ_fPu238/σ_fPu239	1.036±0.035	1.034±0.035	1.047±0.035
σ_fPu240/σ_fPu239	1.002±0.030	1.010±0.030	1.034±0.030
σ_fPu241/σ_fPu239	0.998±0.015	0.990±0.015	0.977±0.015
σ_fPu242/σ_fPu239	0.975±0.020	1.046±0.020	1.010±0.020
σ_fAm241/σ_fPu239	0.924±0.030	0.940±0.030	0.974±0.030
σ_fAm243/σ_fPu239	0.993±0.040	0.999±0.040	1.029±0.040
σ_fCm244/σ_fPu239	1.125±0.030	1.093±0.030	1.133±0.030
σ_cU238/σ_fU235	0.980±0.025	0.947±0.025	0.943±0.025
σ_cAu197/σ_fU235	±0.045	-	±0.045
σ_cNp237/σ_cU238	0.931±0.050	0.921±0.035	0.954±0.050
σ_cNp237/σ_fU235	1.013±0.035	-	0.970±0.035

SODIUM VOID REACTIVITY MEASUREMENTS

performed on various heights of the central part of the core.
Calculated results are obtained

by **perturbation theory** for BFS67-1 and BFS67-2 sodium void reactivities with a **3D cell description of the voided cell.**

Sodium Void Reactivity Worth				
	BFS67-1		**BFS67-2**	
voided parts	Experiment (in pcm)	C/E	Experiment (in pcm)	C/E
3+4+5+6; 31 fuel rods	**29.8**±1.4	0.89	**90.4**±3.9	1.00

Introduction of Np237 in the core fuel **increases the Na void reactivity worth,**
effect correctly reproduced by the calculation.
Calculated result overestimates the experimental trend,
acceptable for safety considerations.

ABSORBER REACTIVITY WORTH MEASUREMENTS

Two types of absorber pellets were used:
natural boron carbide and
enriched (81.7% B-10) boron carbide.

The absorber reactivity worth is a dynamic movement of a "long rod"
from a position where the lower part (sodium) is in the core
to a position where the upper part (boron) is inserted in the core.

The reactor power is decreasing from a high level, rapidly with the insertion of the rod.
The reactivity worth is obtained by following the power history using the Carpenter method.

Absorber type	Height of absorber column (mm.)	BFS-67-1	BFS-67-3B	BFS-67-3	BFS-67-2
B_4C enr.	381.3	-2.16±0.12	-2.13±0.13	-2.10±0.12	-2.06±0.12
B_4C enr.	191.6	-1.26±0.06	-1.20±0.06	-1.20±0.06	-1.15±0.06
B_4C nat.	380.8	-0.879±0.039	-0.825±0.036	-0.809±0.035	-0.787±0.035
B_4C nat.	190.5	-0.493±0.021	-0.455±0.020	-0.455±0.020	-0.433±0.017

A decrease of the absorber reactivity worth with the Neptunium content can be noted.

CENTRAL REACTIVITY COEFFICIENTS (CRC)

measured in the centre of the core using an oscillation method.

Central Reactivity Worth Ratios $R_i(l=0)/R_{235}(l=0)$ $[10^3]$

(l - mean chord of a sample)

Isotope (i)	BFS-67-1	BFS-67-3B	BFS-67-2
U238	-67±2	-54±2	-46±1
Li6	-406±4	-	-
B10	-996±15	-784±15	-716±10
C12	-4.4±0.2	-9.7±0.2	-12.5±0.3
H	45±2	-66.0±1.3	-
Pu239	1330±20	1370±20	1380±20
Np237	-250±10	-112±4	-52±10
Am241	-238±10	-80±20	-28±15
Na	-4.7±0.4	-9.1±0.3	-13.1±0.5

CONCLUSIONS

Experimental configurations have been established **at the BFS facility** (IPPE/Obninsk)
within a **France/Russia** fast reactor collaboration
for validating the Neptunium burning in fast reactors.
Parametric approach with **different Neptunium fuel contents** (6.5%, 13.1%)

Transposition to full power reactor performed
with the **JEF2/ECCO/ERANOS** calculational scheme and
with the **ERALIB1/ECCO/ERANOS** calculational scheme
with a 3 dimensional cell description (to reproduce the precise experimental conditions)
The introduction of Neptunium introduces **no significant discrepancies**

Neptunium in the core **increases the sodium void reactivity worth,**
decreases the control rod worth of up to 15%.
Linear dependence of the measured parameters to the Neptunium content